SAN ANTONIO

# SIGGRAPH 2002


# Soft Things

## Robust Treatment of Collisions, Contact and Friction for Cloth Animation

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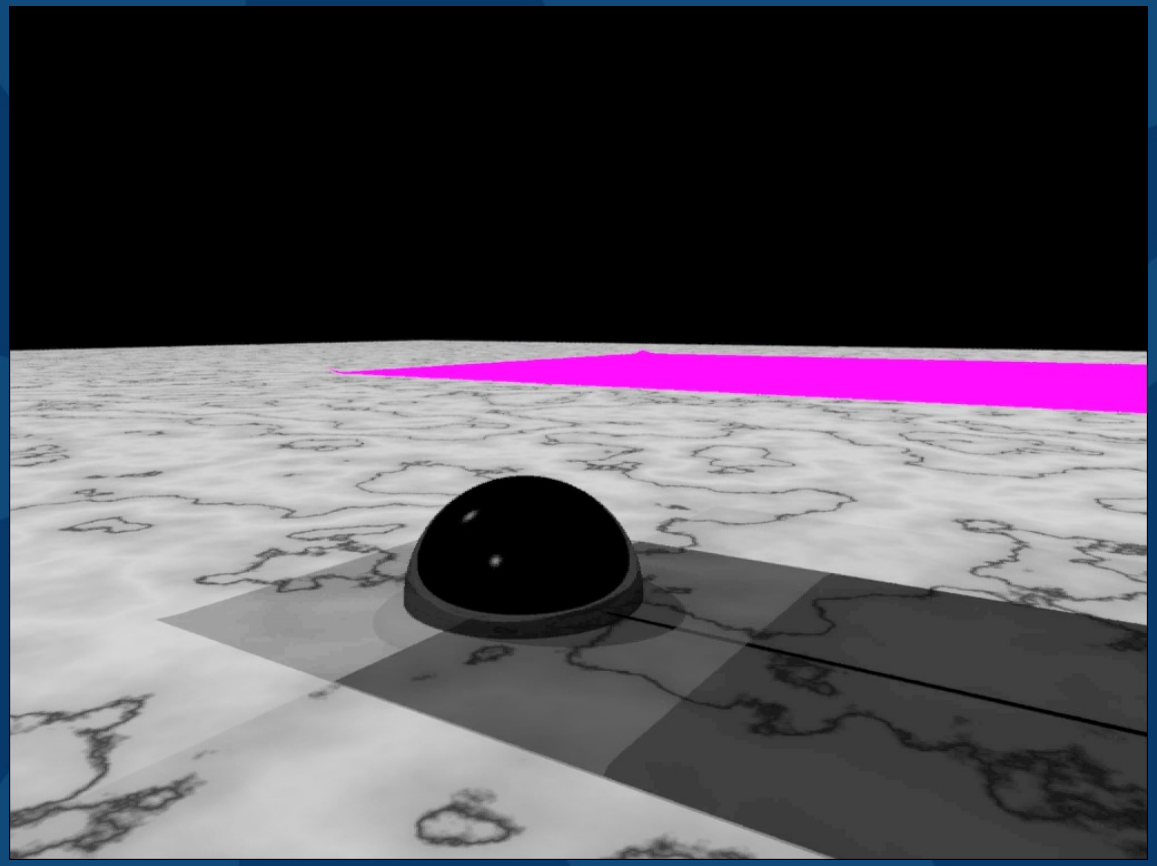
# An example of our algorithm

- 1.2 million triangles
- Thousands of contacts per timestep
- ~1 day of computation on a laptop



# First problem: sheer size

- **Every node is on the surface, surface folds easily**
  - 10,000+ collisions per time step easily possible when cloth folds over onto itself
  - Too expensive to resolve in time order

# Second problem: low tolerance

- **Cloth is very thin –**
  **once it interpenetrates, it pops out**
  **the other side**
  - In most interesting folding, effect is too severe to try to untangle after the fact
- **Need to stop all interpenetration**

# One solution: repulsion forces

- **Put a repelling force-field around cloth**
  - e.g. Terzopoulos et al, Moore & Wilhelms, Carignan et al, Lafleur et al, Baraff & Witkin

  - Good for automatically handling contact
  - If set correctly, models cloth thickness and compressibility (e.g. the fuzz on a towel)
  - When resolved, smooth and accurate

# Problems with repulsion forces

- **Not robust**
  - Can miss multiple or fast collisions
  - Once on wrong side, pushes the wrong way
- **Partial fix: increase size and strength**
  - Makes cloth “float”
  - Numerical difficulties

# Another solution: geometric collisions

- **Consider trajectories over timestep, find all collisions, apply impulses**
  - e.g. Provot ‘97
  - If rounding error properly handled, never misses a collision

# Problems with geometric collisions

- **Difficult to resolve multiple collisions simultaneously**
  - Fixing one may cause others…
  - Expensive to iterate too long
- **Triangles resist sliding over each other**
  - Catastrophic error: “chainmail” friction inconsistent with physics

# How can do we do better?

- **Combine the two approaches!**
  - First apply repulsion forces – quickly and accurately handles almost everything
  - Check new trajectories geometrically, eliminate all remaining intersections
- **Well-conditioned and bullet-proof, almost as cheap as repulsions alone**

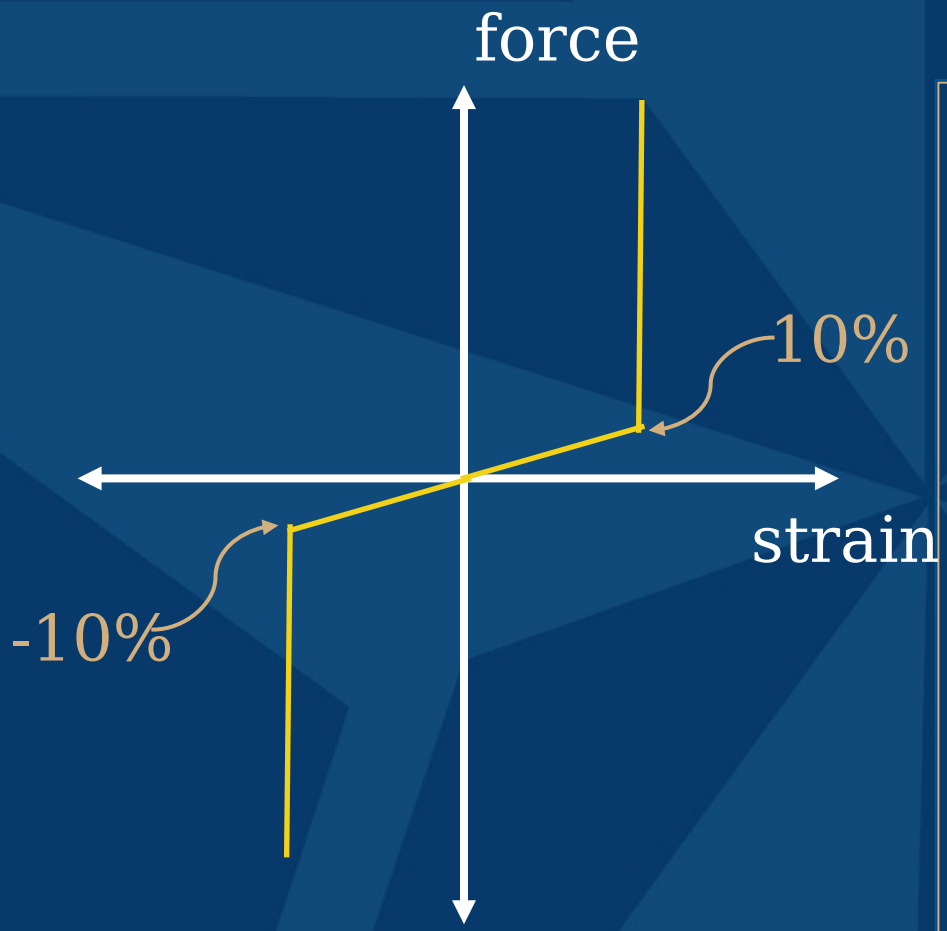
# Time stepping

- Advance $x$ and $v$ (internal cloth dynamics)
  - $(x^n, v^n) \rightarrow (x^{n+1}, v^{n+1})$
- Get average $v$ over step
  - $v^{n+\frac{1}{2}} = (x^{n+1} - x^n)/\Delta t$
- Adjust $v^{n+\frac{1}{2}}$ for repulsions/friction
- Adjust $v^{n+\frac{1}{2}}$ to resolve all geometric collisions
- Get new $x$ from modified $v^{n+\frac{1}{2}}$
  - $x^{n+1} = x^n + \Delta t\, v^{n+\frac{1}{2}}$
- Advance modified $v$ (internal cloth dynamics)
  - $v^{n+1} = v^{n+\frac{1}{2}} + \frac{1}{2}\Delta t\, a(x^{n+1}, v^{n+1})$

# Internal cloth dynamics

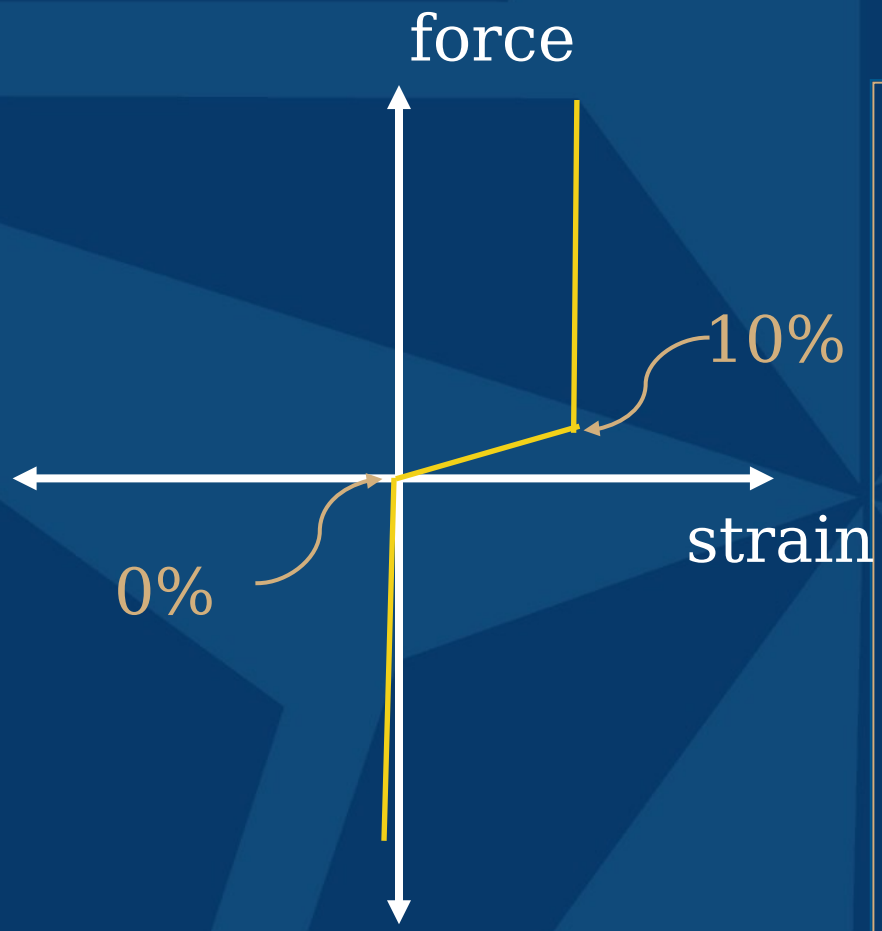
- **Could be anything! (Use existing code)**
  - One implicit step, many Runge-Kutta steps, masses and springs, finite elements, …
- **We use masses and springs, Provot ’95**
  - Additional impulses limit excess strain rate: helps keep cloth together after collisions

# Limiting strain




- **Like Provot ’95, apply impulses to limit strain**
- **Implicit integration (Gauss-Seidel) of biphasic springs**

# Limiting strain




- Like Provot ’95, apply impulses to limit strain
- Implicit integration (Gauss-Seidel) of biphasic springs
- Zero compression
  - Causes buckling
  - See next talk…

# Repulsion forces

- **Check for triangle/point, edge/edge at old positions**
- **Limit repulsion to a fraction of cloth thickness – eliminate “kicks”**
- **Normal force gives Coulombic friction**
  - If $v_T$ is tangential velocity before friction, $\Delta v_N$ is normal repulsion impulse, then $v_T^{\text{friction}} = \max(|v_T| - \mu \Delta v_N, 0)\, v_T/|v_T|$

# Resolving geometric collisions

- **Use Provot ’97:**
  - Apply inelastic collision impulses
  - Check for additional collisions
  - After 3 rounds of impulses, solidify inter-colliding patches into rigid “impact zones”
- **To prevent cloth creeping through with round-off error, enforce minimum separation**

# Subdivision

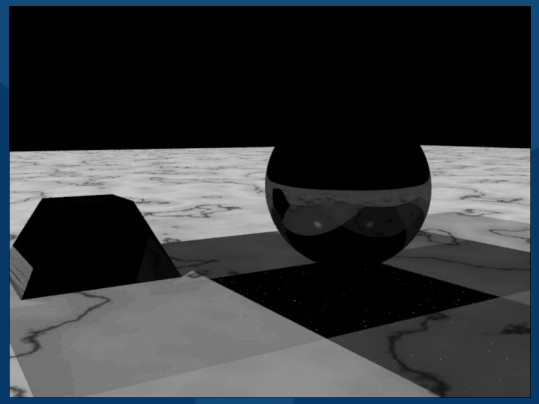
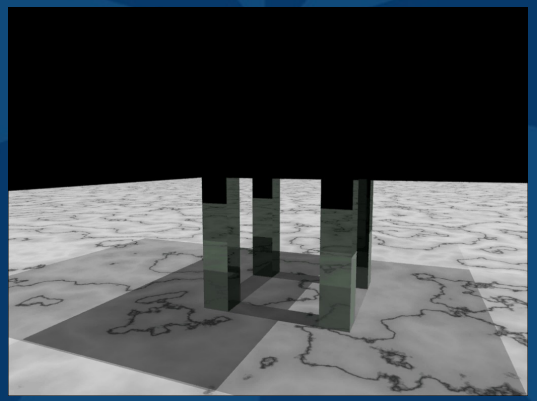
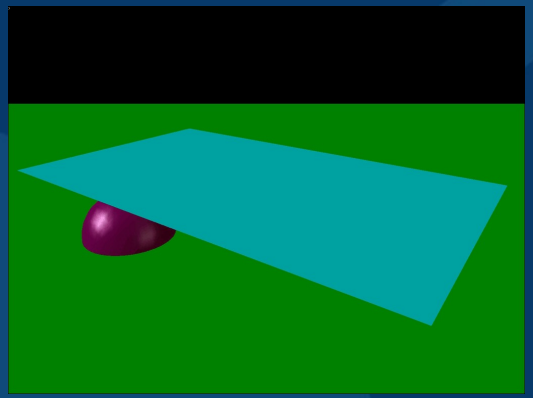
- **Sharp folds barely resolved in simulation**
  - Unacceptable for rendering
- **Can subdivide mesh in each frame**
  - We use Loop
- **Convex-hull property helps, but… self-intersections and object-intersections may be introduced**

# Collision-aware subdivision

- **Modify subdivision to avoid collisions**
  - Start with refined mesh (linear rule)
  - Move to smooth subdivision positions
  - Check “motion” for collisions, scale down “velocities”

# Results

- **Minutes per frame on a laptop, 15k-40k simulation nodes, subdivided twice**

# Thanks!

- Igor Neverov, Neil Molino, Joey Teran, Henrik Wann Jensen
  – rendering examples
- Sebastian Marino, Cliff Plumer, Andy Hendrickson, and Lucasfilm
  – Yoda